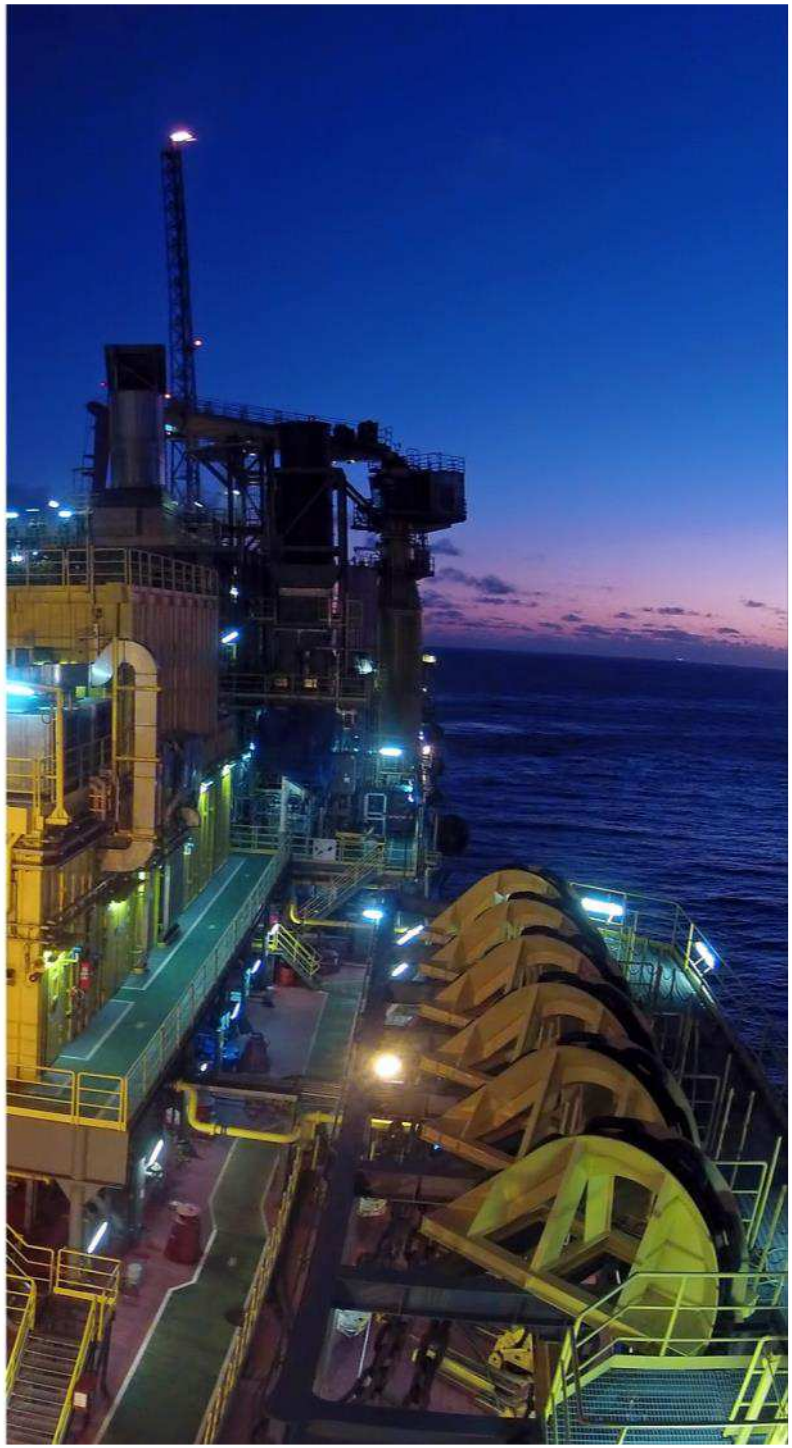


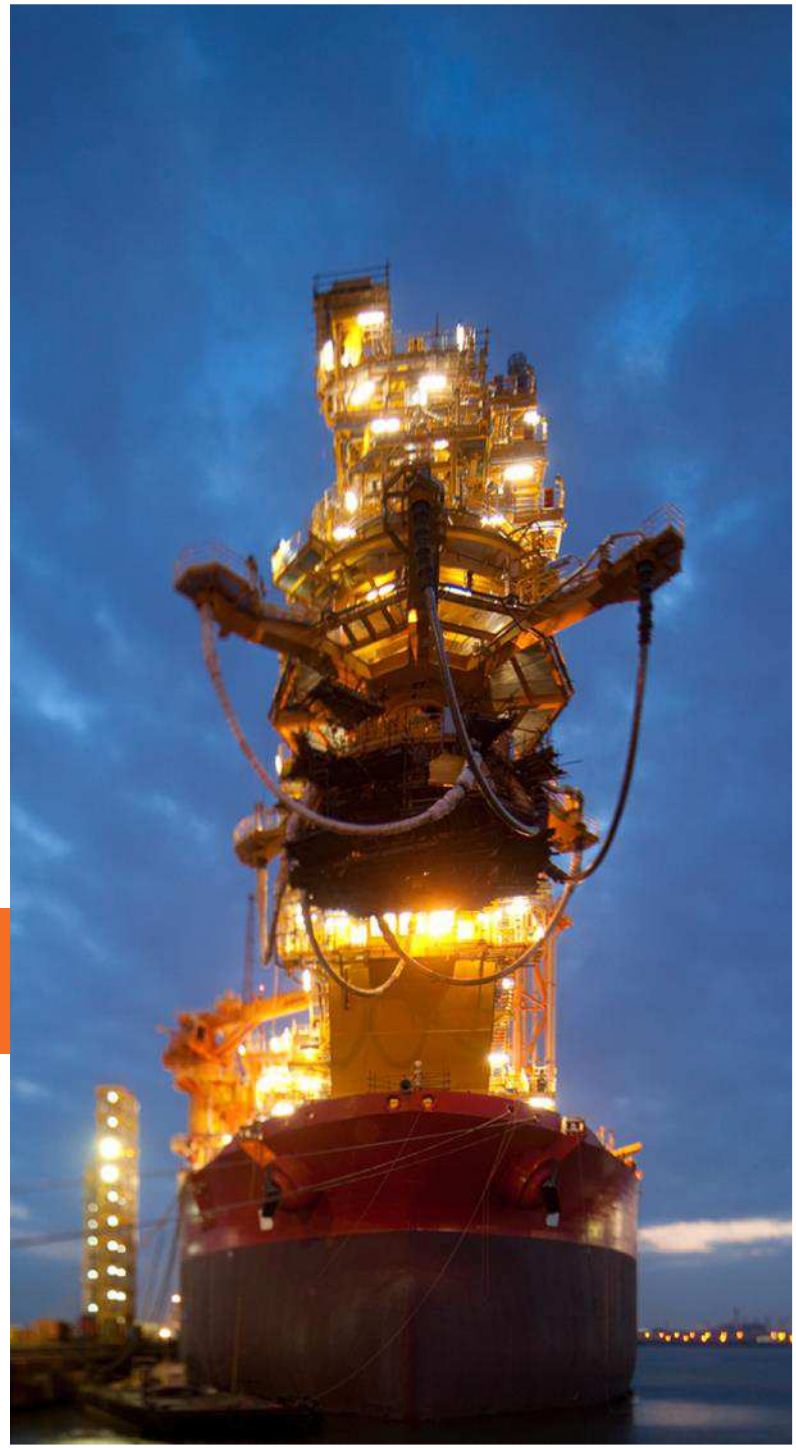
2/21/2016

KIVI Lecture

Novel Wave Energy Converter: Promising Future

18 February 2016

Ambroise Wattez & Rick van Kessel
Schiedam



Novel Wave Energy Converter
Agenda

1. General introduction to SBM Offshore
2. General introduction to Renewable Energy
3. Wave Energy: an immense and untapped resource
4. State-of-the-art of Wave Energy Converters (WECs)
5. SBM S3 WEC: a change in paradigm

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1. Introduction to Electroactive Polymers
2. Application of EAP to S3 WEC
3. Ongoing development activities
4. Test facilities

- Q&A

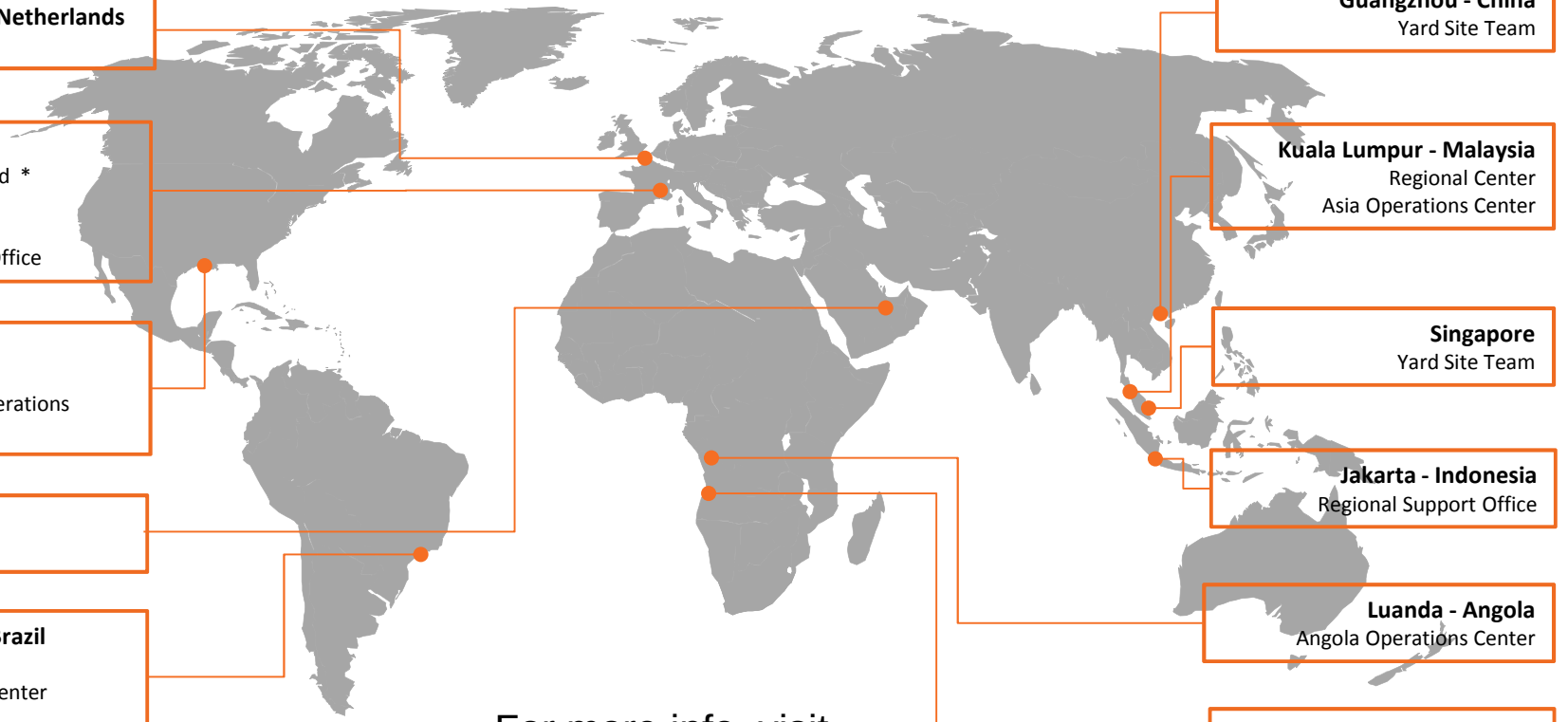
Disclaimer

Some of the statements contained in this presentation that are not historical facts are statements of future expectations and other forward-looking statements based on the presenters' current views and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance, or events to differ materially from those in such statements. Such forward-looking statements are subject to various risks and uncertainties, which may cause actual results and performance of the Company's business to differ materially and adversely from the forward-looking statements.

Should one or more of these risks or uncertainties materialize, or should underlying assumptions prove incorrect, actual results may vary materially from those described in this presentation as anticipated, believed, or expected. SBM Offshore NV does not intend, and does not assume any obligation, to update any industry information or forward-looking statements set forth in this presentation to reflect subsequent events or circumstances.

SBM Offshore Worldwide

SBM offices around the World



Schiedam – the Netherlands
Regional Center

Monaco
Management Board *
Group Functions *
Regional Center
Operations Head Office

Houston - USA
Regional Center
North-America Operations Center

Dubai - UAE
Yard Site Team

Rio de Janeiro - Brazil
Regional Center
Brazil Operations Center
Construction Yard

Guangzhou - China
Yard Site Team

Kuala Lumpur - Malaysia
Regional Center
Asia Operations Center

Singapore
Yard Site Team

Jakarta - Indonesia
Regional Support Office

Luanda - Angola
Angola Operations Center

Porto Amboim - Angola
Construction Yard

For more info, visit
http://www.sbmoffshore.com

*: SBM Head Office to be based in Amsterdam (Netherlands) as of Q3-2015

Listed on the Amsterdam Stock Exchange
Over **7,500** people worldwide

Not shown: 10 shore bases

SBM Offshore – Unparalleled expertise of floating systems

TECHNOLOGY | PROJECT EXECUTION | OPERATIONS | FINANCE & LEASE

Focus on top-end segment
- FPSOs
- Turret Moorings
- Turnkey Sale or Lease & Operate

Enlarging the envelope
- Floating LNG (FLNG)
- Semisubmersible & TLP production units
- Marine Renewables (MC, since 2006)

Leader in Floaters & Mooring systems

Over 500 offloading terminal supplied

Over 50 mooring systems supplied

> 250 years cumulated experience

19 leased units operated by SBM

$ 3.4B turnover in 2014

SBM Vision

To be the trusted partner of choice in the development of complete offshore floating solutions for the world's energy companies

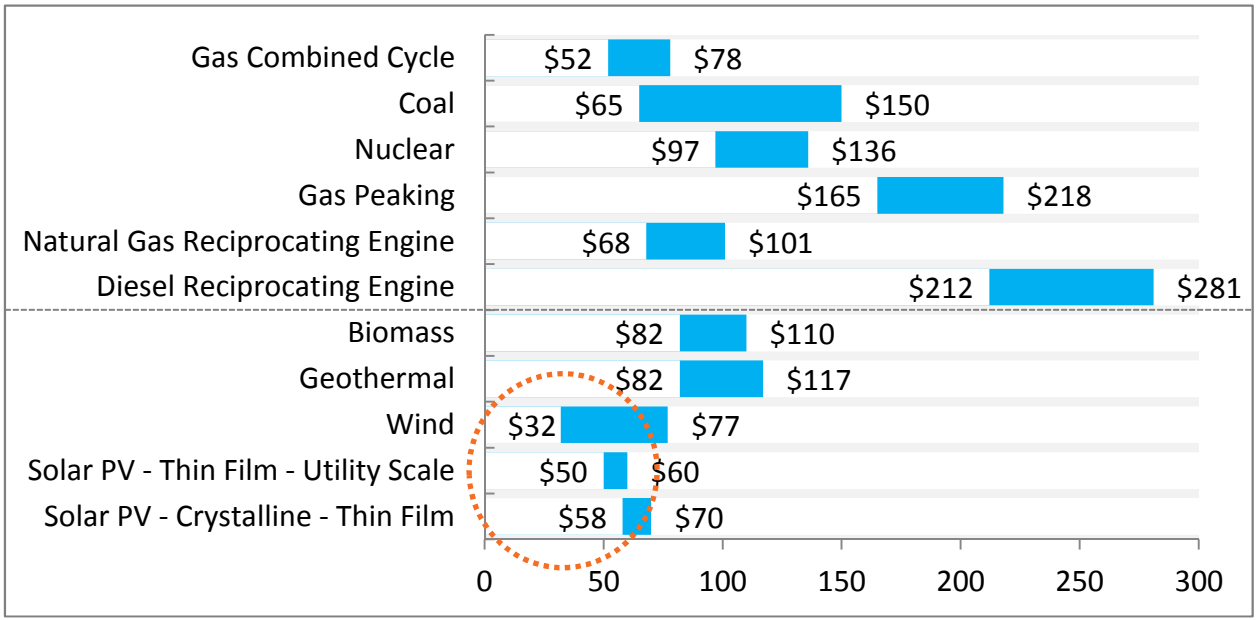
Renewable Energy

Introduction

Are Renewable Energies credible energy sources?

- December 2014: Scotland Wind Energy alone provided 164% of the country electricity demand
- In 2015 $329 Bn CAPEX were invested in Renewable Energy worldwide
- LCOE of solar PV divided by 6 in 6 years (divided by 50 in 30 years)
- Today, Wind and Solar are the cheapest energies on the Planet

YES!



LCOE of various energy sources

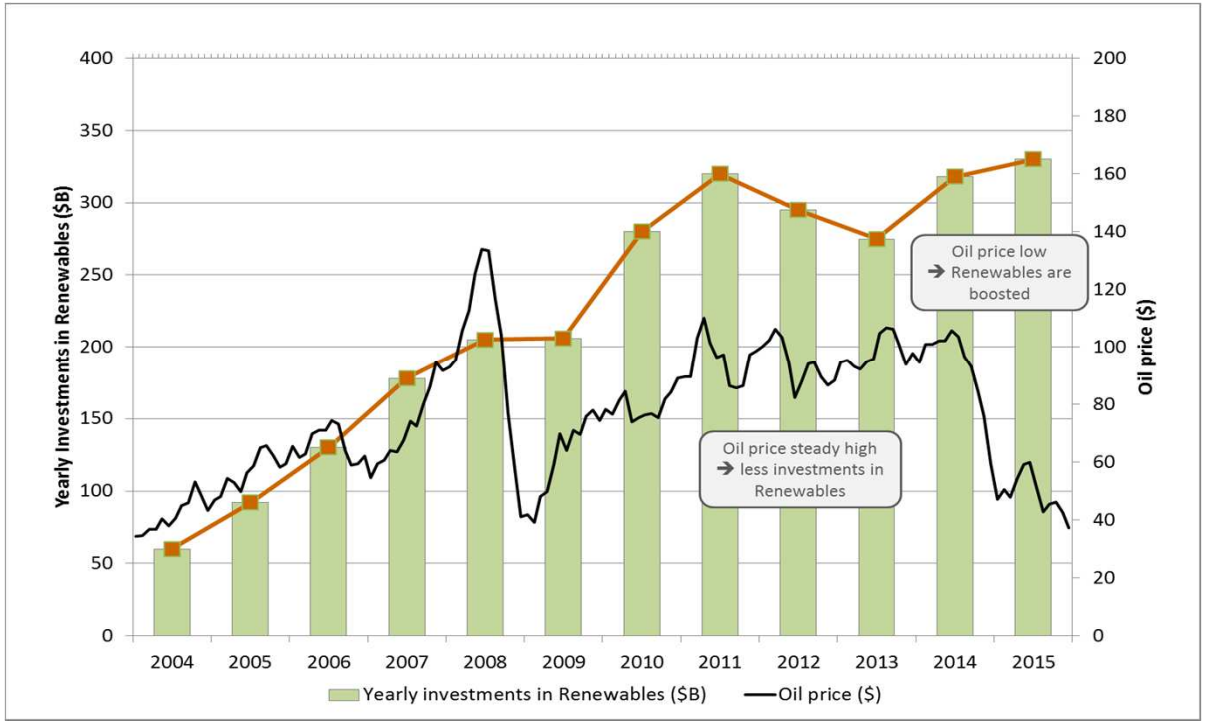
Source: Lazard 2015

Renewable Energy Market

Renewables market has been proven to be resilient to oil price so far

Renewables and O&G do not really compete

- The continued development of renewable energies has become inevitable due to:
  - Enhanced social acceptance
  - Strong political support
  - Competitiveness with traditional energy sources
  - Localization
  - Massive resource
- COP 21 in Paris has strengthened the commitments towards Renewables



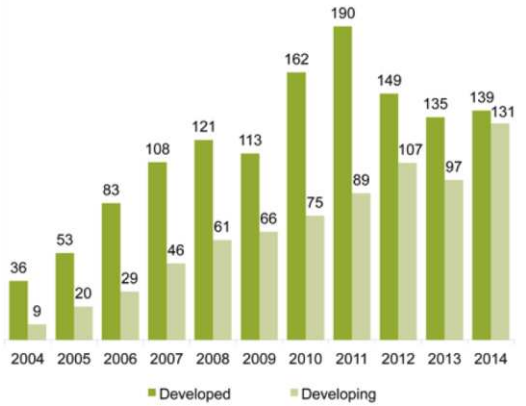
http://www.mckinsey.com/insights/energy_resources_materials/lower_oil_prices_but_more_renewables_whats_going_on

http://www.bloomberg.com/news/articles/2016-01-14/renewables-drew-record-329-billion-in-year-oil-prices-crashed

Renewable Energy Market

- **The oil price is low, yet investments in Renewables have never been higher**
  - In 2013, Renewables provided > 50% of all new power plants capacity
  - Developing countries are the largest growth market for Renewables despite low oil price
  - Scotland targets 100% of energy consumption from Renewables in 2020

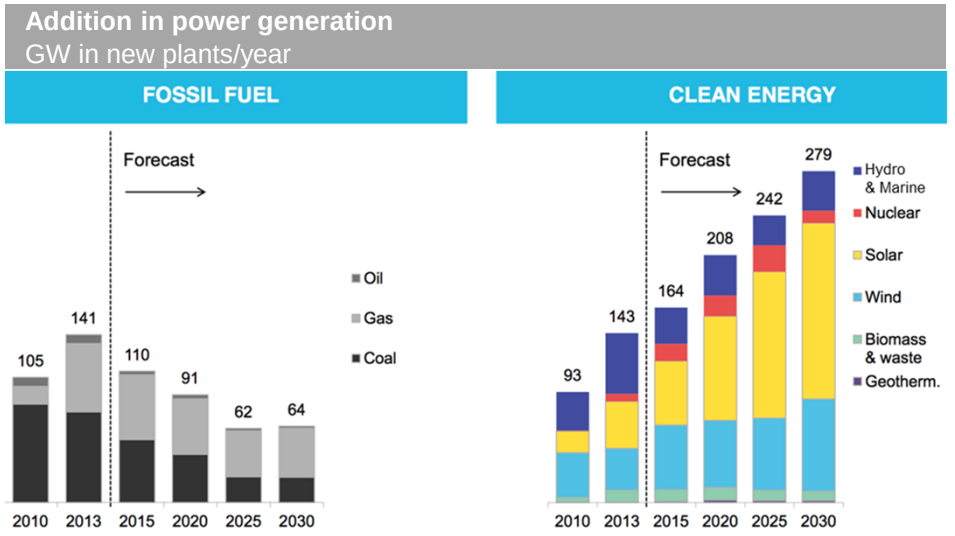
FIGURE 4. GLOBAL NEW INVESTMENT IN RENEWABLE ENERGY: DEVELOPED V DEVELOPING COUNTRIES, 2004-2014, $BN



Source: Bloomberg 2015

- Penetration of Renewables is intimately linked to the development of **smart-grid and/or energy storage solutions**

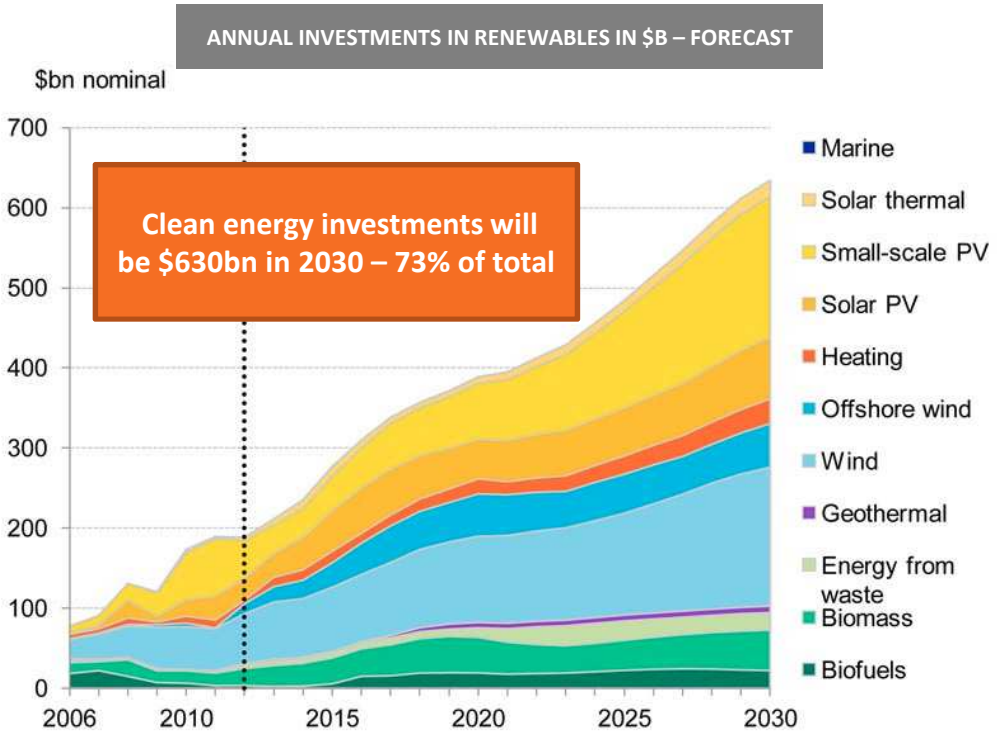
- Solar and Wind are currently reaching grid parity worldwide



Source: Bloomberg 2015

Renewable Energy Market

- Renewables market is driven by the LCOE (Levelized Cost of Electricity)
- Renewables are generally less mature than conventional energy sources, and still have a strong potential for further LCOE reduction
- **Over $8 trillion** is forecast to be invested in Renewables **over the next 25 years**, being more than twice the investment in coal, oil and gas combined on the same period

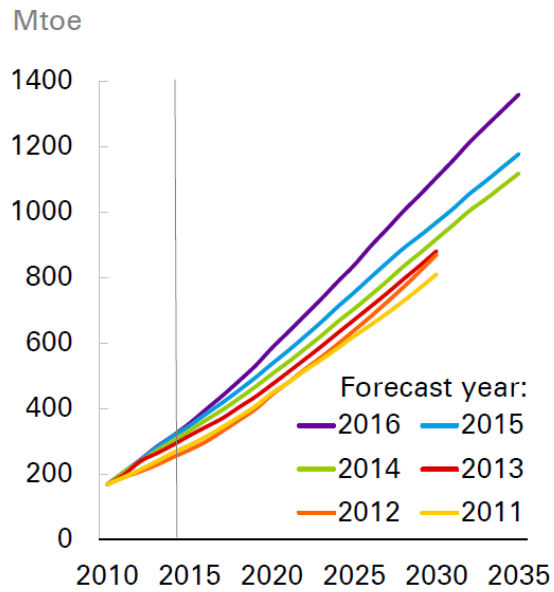


Source: Bloomberg 2013

Renewable Energy Market

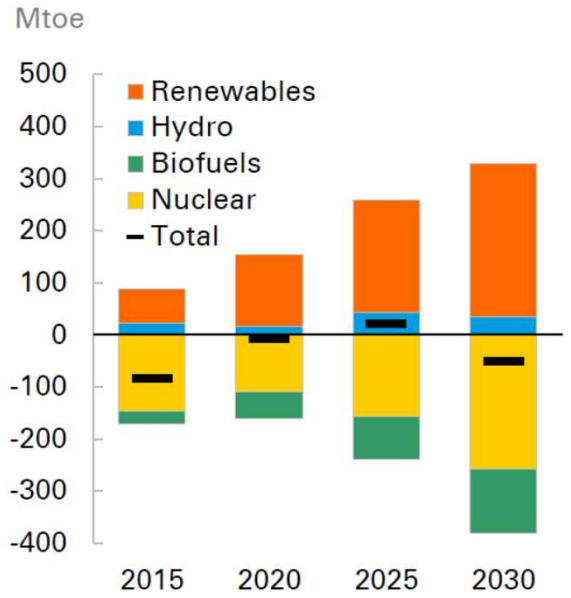
- Renewables have been revised up repeatedly…

RENEWABLE POWER FORECASTS



Source: BP Energy Outlook 2016

REVISIONS TO NON-FOSSIL FUELS VS 2011 OUTLOOK

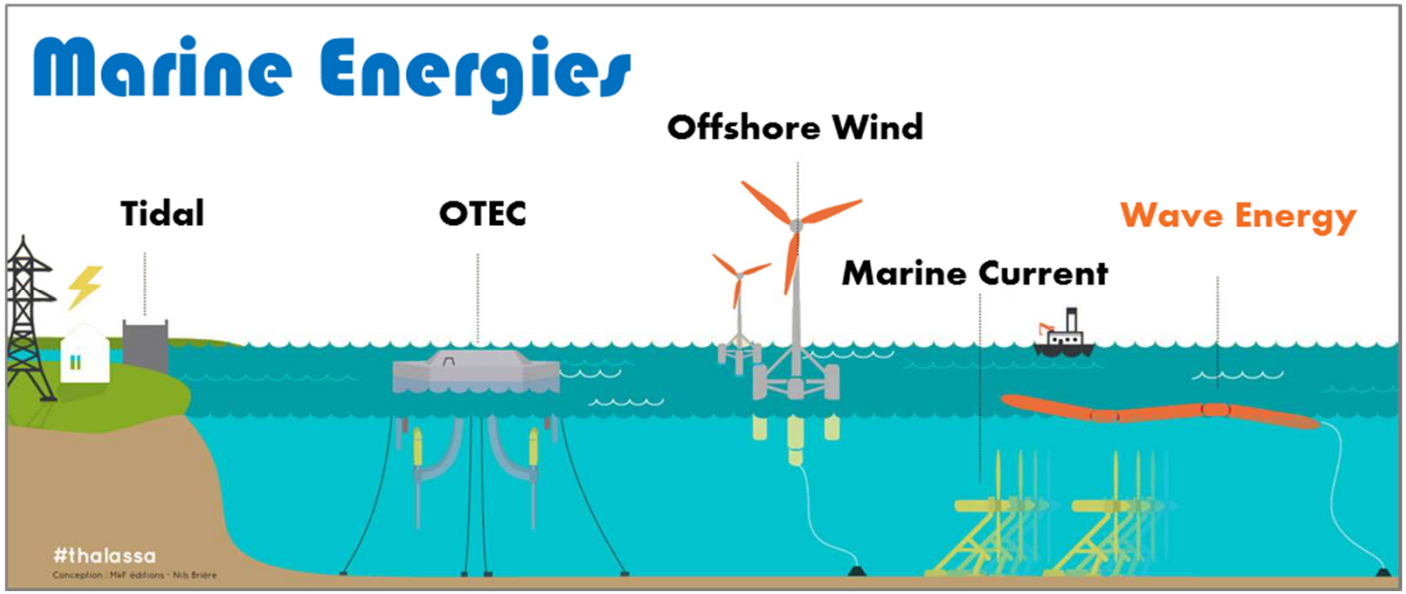


Source: BP Energy Outlook 2016

- … while fossil fuels have been revised down

Renewable Energy Market

- Renewable energy is currently moving offshore
  - Offshore wind market in 2015 > $15Bn
  - New energy sources available:



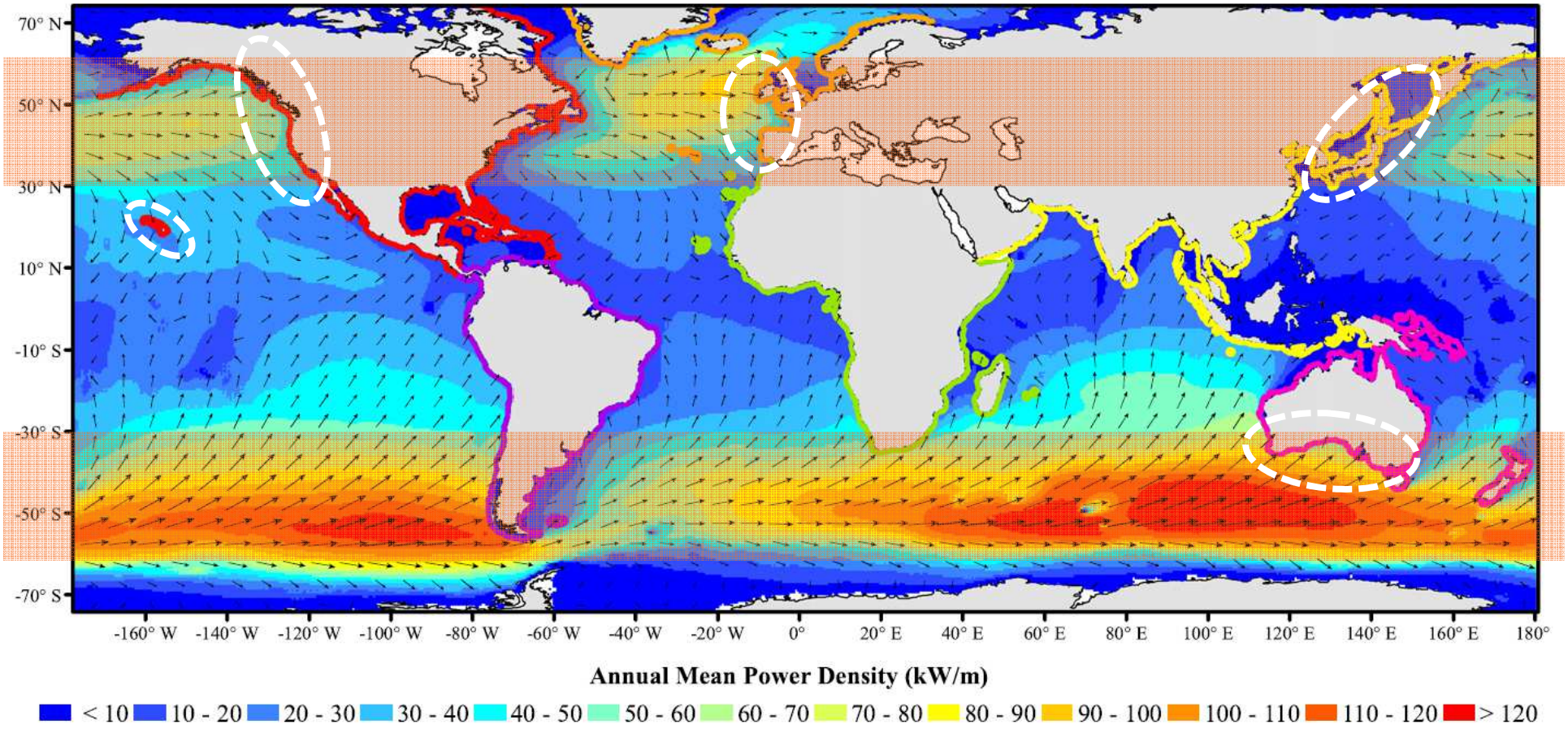
Source: France 3 website

- This creates opportunities for offshore contractors as these projects require strong offshore experience

Wave Energy

An immense and untapped resource

Wave Energy



Source: Gunn et al. 2012

- West coasts (US / Europe / JP): good resource, strong political drive towards renewables
- Island markets: islands pay premium price for energy ➔ need for local energy production

Wave Energy

- Wave energy alone can provide **2.11 TW** of average power around the globe (source Gunn et al. 2012)
  - ✓ This is approximately the total planet electricity consumption

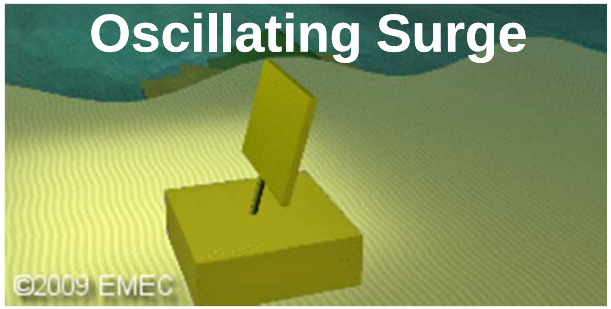
- UN: **50%** of the world's population lives **within 60 km of the sea**
  - Natural match between the energy localization and its final consumption

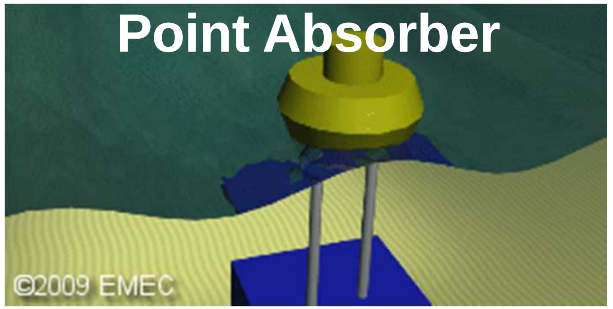
- Wave energy is an **immense and untapped resource**
  - Attempts to harness wave energy have suffered from a lack of offshore expertise

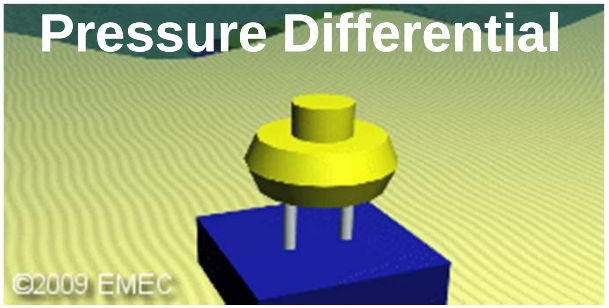
Wave Energy

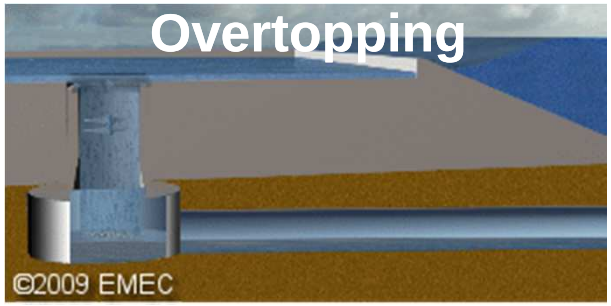
State of the art and Generation 1 devices

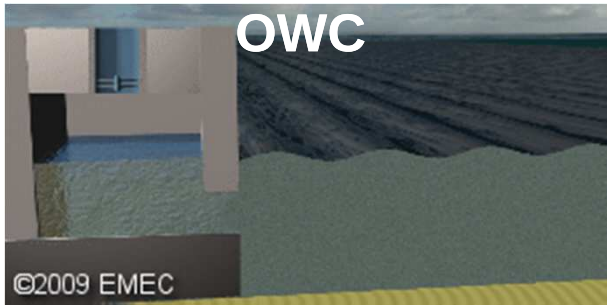
Wave Energy – Generation 1 devices











Rigid systems are inherently limited

- ✖ High structural costs
- ✖ Load path concentration on Power Take-Off elements
- ✖ Mechanical Power Take-Off ➔ costly O&M
- ✖ Optimized for 1 wave period

TRUE FOR ALL CONVENTIONAL SYSTEMS

SBM S3 WEC

A Paradigm shift

SBM S3 WEC – A Paradigm shift

Conventional (rigid) systems are inherently limited

- ✖ High structural costs
- ✖ Energy / stress concentration on Power Take-Off elements
- ✖ Mechanical Power Take-Off ➔ costly O&M
- ✖ Narrow & fixed absorption bandwidth

Generation 1

Breakthrough technology required

- ❑ Merged power conversion function and hull structure
- ❑ No complex mechanical parts
- ❑ No routine maintenance
- ❑ Flexible and silent
- ❑ Large absorption bandwidth

Generation 2

SBM S3 WEC – A Paradigm shift

SBM S3 CONCEPT:

Fully flexible tube filled with water, closed at both ends

➔ Multimodal response (standing waves)

Energy conversion system = Electro-Active Polymers (EAP)

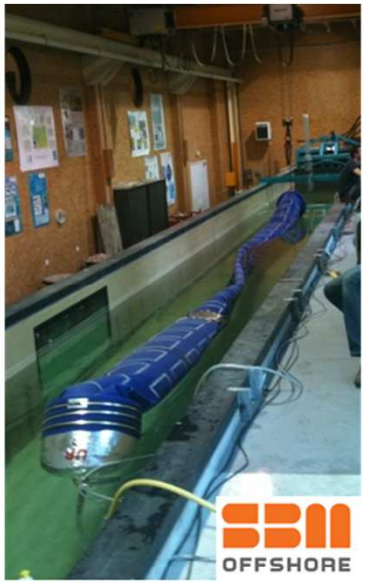
EAP-based PTO embedded in the structure

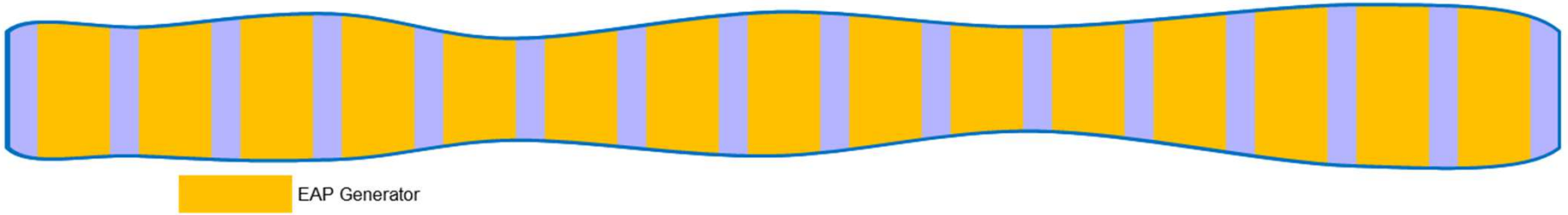
Energy converted DIRECTLY from waves to electricity

Distributed power generation

EAP = roll-to-roll process

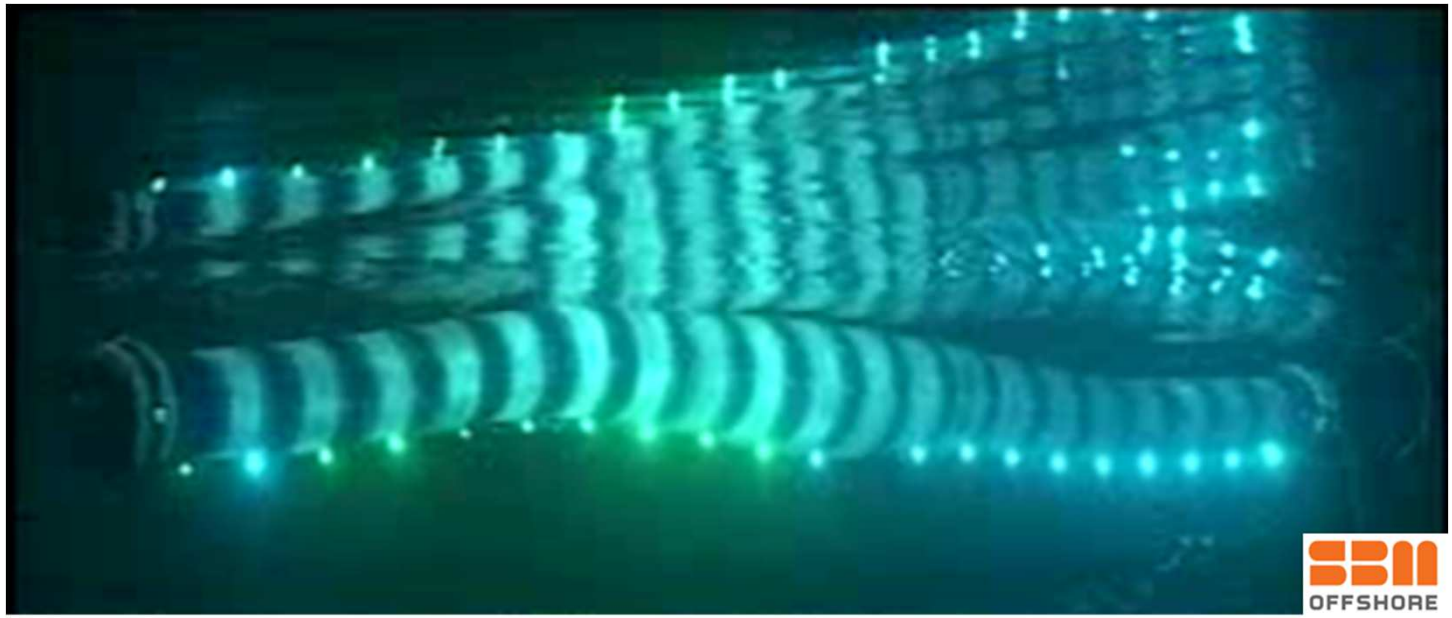
S3 test campaign, ACRI IN, 2010





SBM S3 WEC – A Paradigm shift

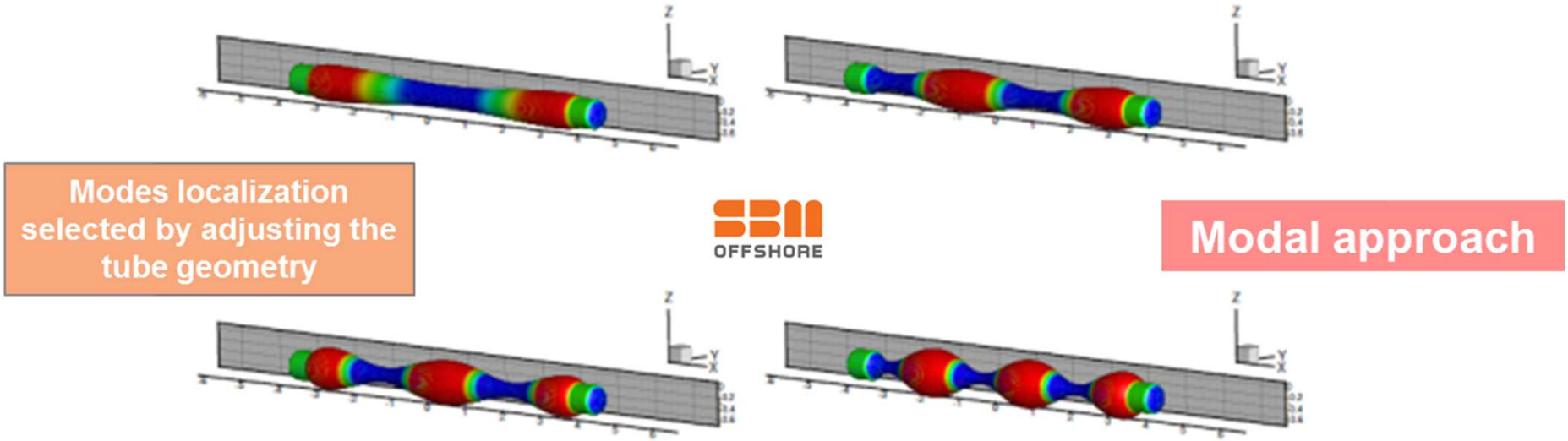
- ✓ Merged power conversion function and hull structure
- ✓ No complex mechanical parts
- ✓ No routine maintenance
- ✓ Flexible and silent
- ✓ Large absorption bandwidth



S3 test campaign, ECN, 2011

SBM S3 WEC – A Paradigm shift
Wave-To-Wire model

- SBM developed a fully coupled numerical model of its S3 WEC that integrates realistic excitations and interactions from the wave excitation to the power generation
- Fundamental response modes used to project forces and motions
- ➔ CPU-friendly calculations thanks to the modal decomposition
- ➔ Time domain model also uses the modal decomposition while being fully coupled



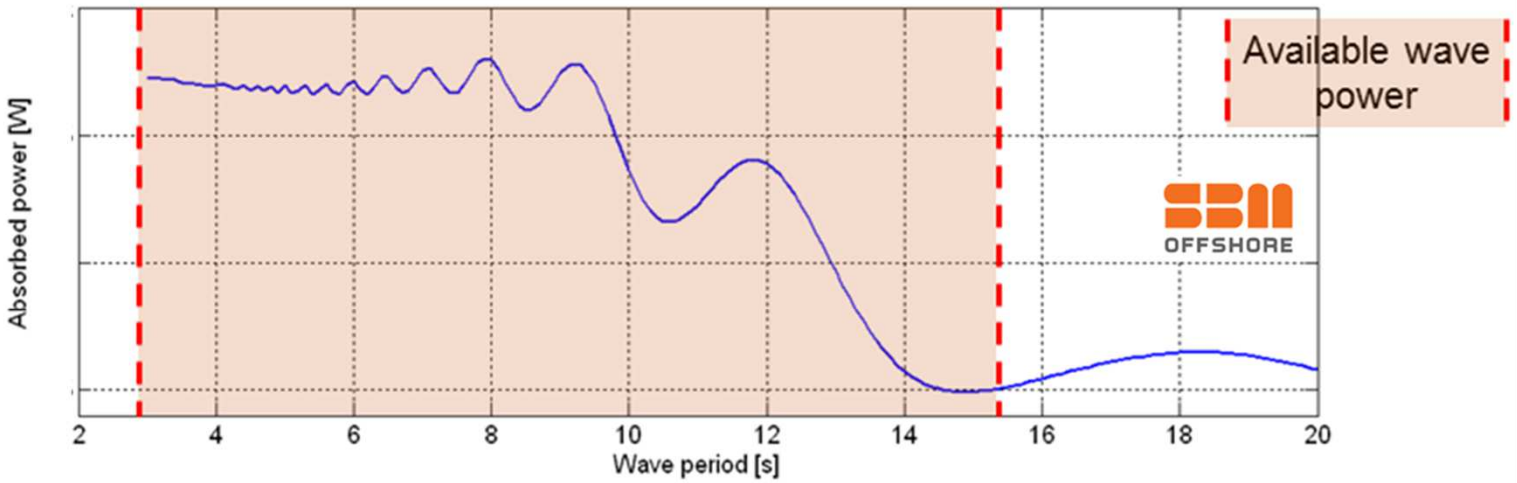
SBM S3 WEC – A Paradigm shift

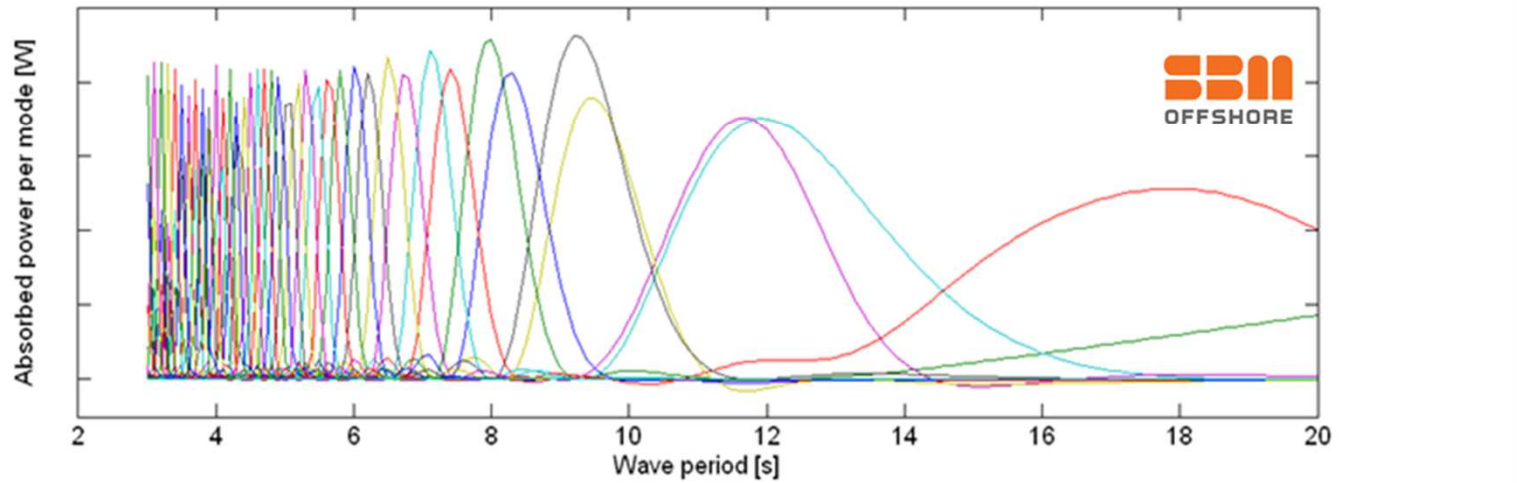
Continuously deformable

Infinite number of degrees of freedom

Infinite number of response modes

Higher capture efficiency



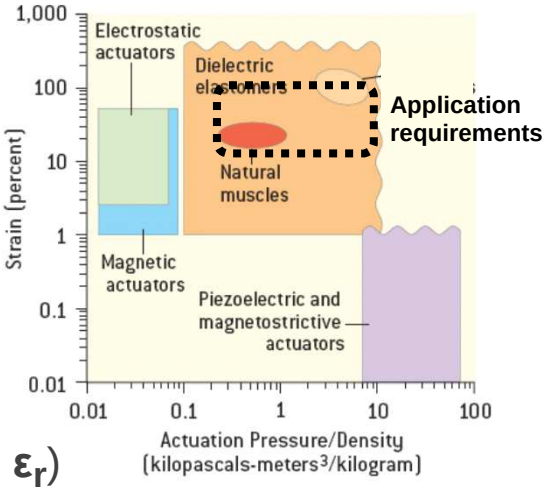


EAP

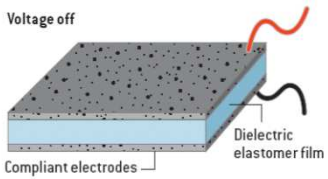
Introduction

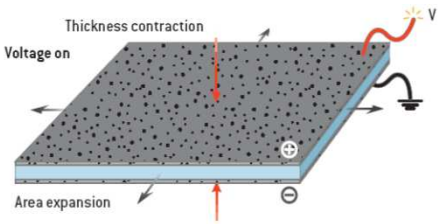
ELECTROACTIVE POLYMERS
What is an electroactive polymer?

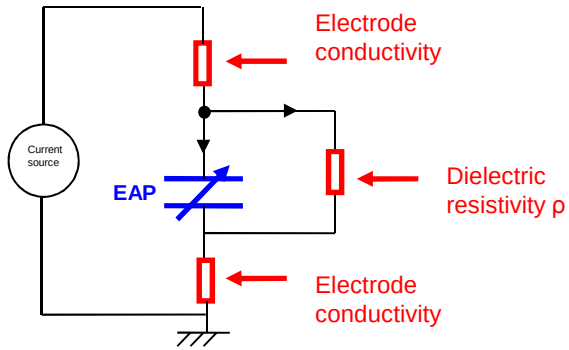
- EAP films are **electrostatic energy transducers**
  - Able to convert mechanical energy into electric energy
  - Passive materials
  - Soft and stretchable
  - High energy density



- Good EAP = good capacitor
  - Ability to handle high electric field stress (high Dielectric Breakdown Strength, **DBS**)
  - Ability to accumulate charges (high dielectric constant, ε_r)
  - Ability to keep charges (high resistivity, **ρ**)
  - Ability to be deformed (**compliant** electrodes, low elastic modulus **Y**)







ELECTROACTIVE POLYMERS
Advantages and applications

- Main advantages:
  - Monolithic structures
  - Soft and flexible
  - Biocompatible
  - Actuation, generation, sensing: seamlessly and simultaneously

Robotics | Biomedical | Automotive

Entertainment | Drives & Controls

Artificial muscles & (bio-mimetic) robotics

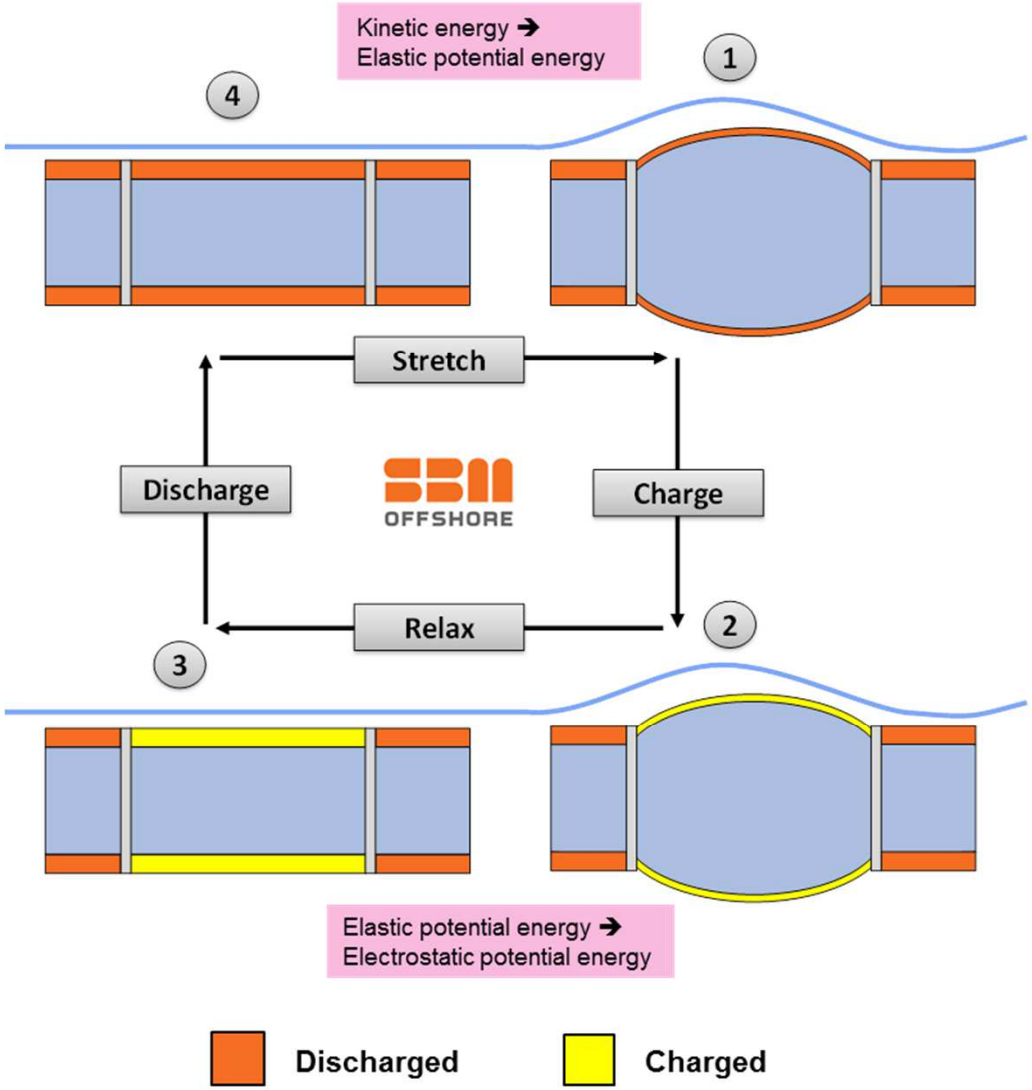
StretchSense flexible sensors

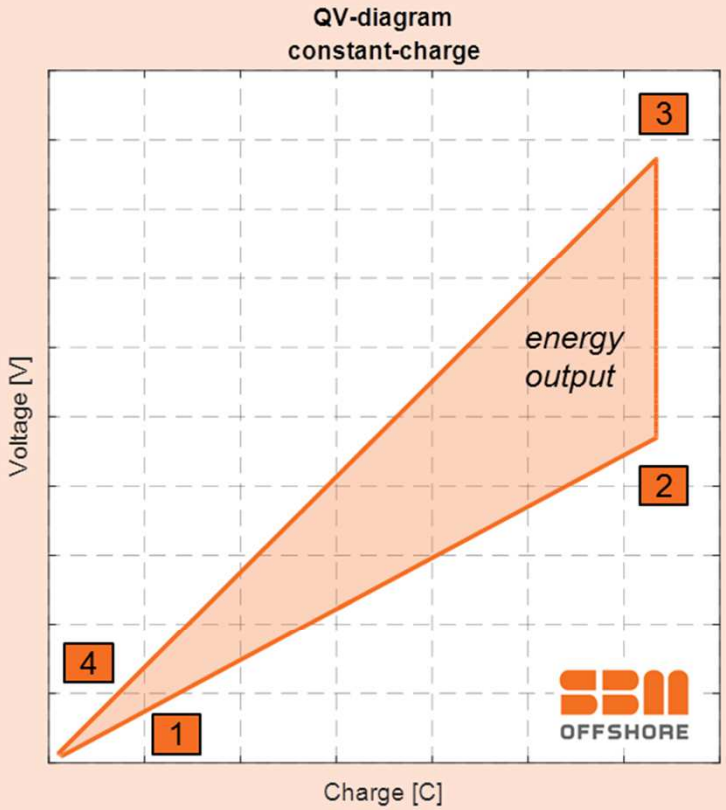
Active Vibration Damping

EAP

Application to S3

ELECTROACTIVE POLYMERS
Application to S3 WEC





ELECTROACTIVE POLYMERS
Harvesting system for the S3 WEC

S3 Harvesting System

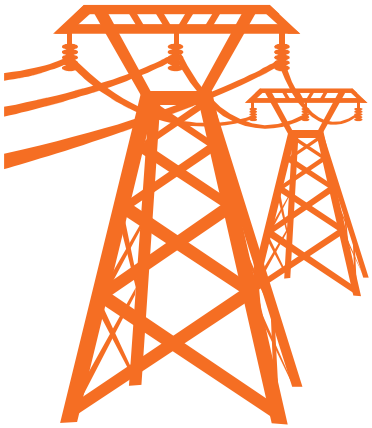
CONTROL

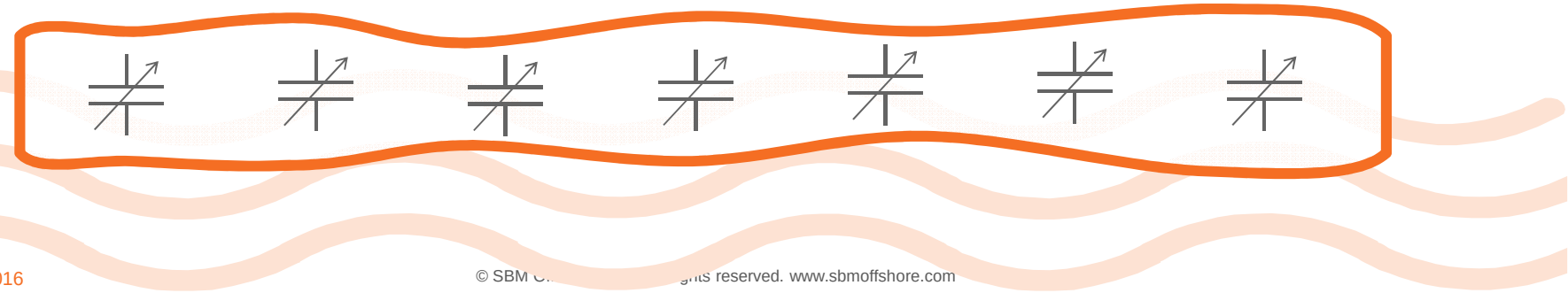
CONVERTER

INSTRUMENTATION

V A λ

GRID INTERFACE

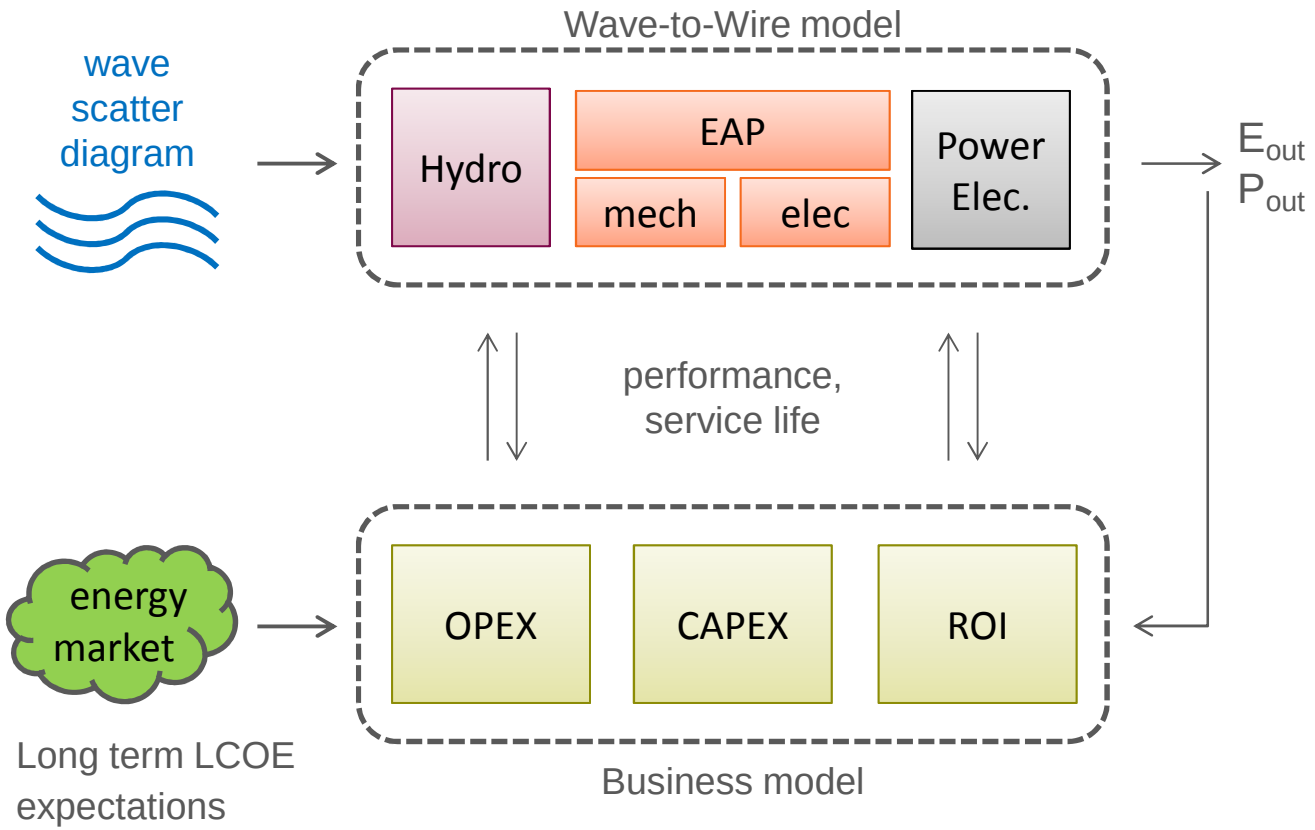




R&D

Ongoing developments

ONGOING RESEARCH & DEVELOPMENT
Main areas of development

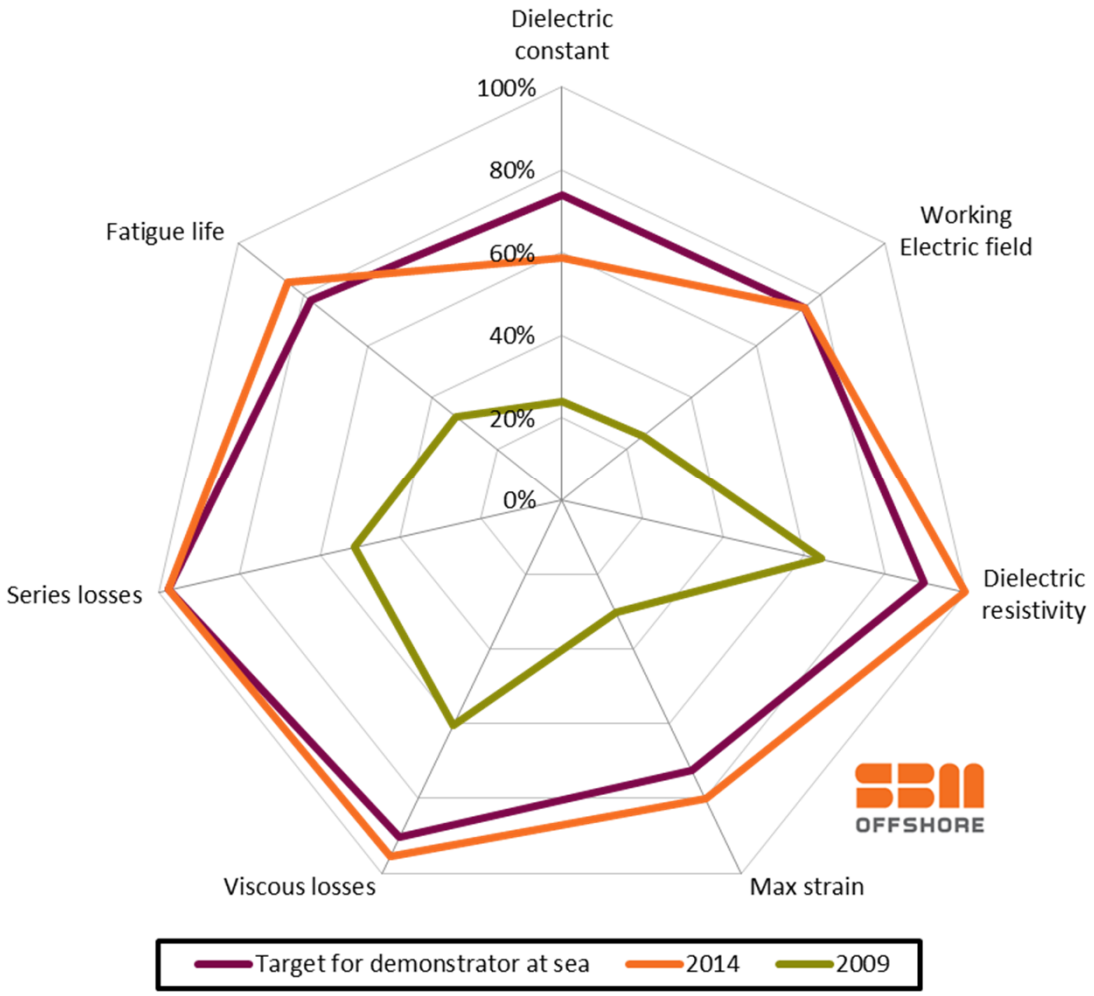


- Business case drives main areas of development:
  - Hydrodynamics
  - EAP material
  - PTO technology
- Validation with several test campaigns and test benches

Working towards small scale prototype

ONGOING RESEARCH & DEVELOPMENT
EAP material

- Development of EAP material specific to WEC in collaboration with first-class universities
  - Energy density
  - Strain
  - Lifetime
  - Losses
- SBM has built a network of expert companies to develop and manufacture high performance EAP film



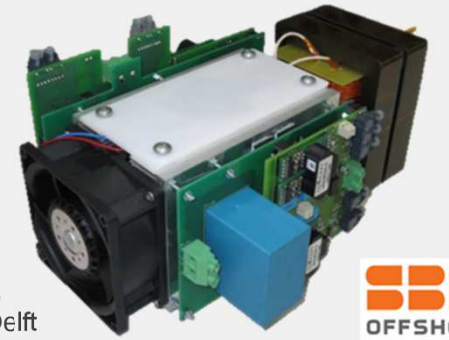
ONGOING RESEARCH & DEVELOPMENT
Power Electronic Converters

Dedicated Converter per EAP generator

- High electric fields: high voltages
- Large power flows: ultra high efficiency needed

- Since 2009, SBM and TU Delft have progressively developed converters with efficiencies >98%

- Input Parallel, Output Series converter
  - Modular concept with Dual Active Bridges
  - Standard IGBT switches: 97.2%
  - Novel SiC switches: 98.5%

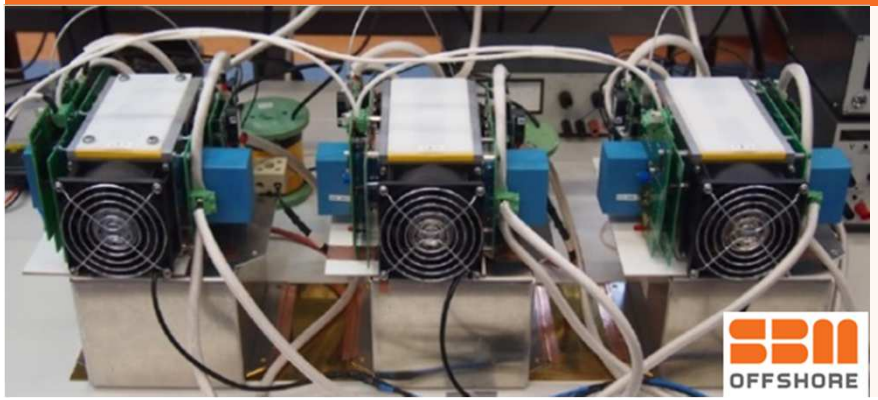


DAB module by
Todor Todorcevic,
PhD student TU Delft

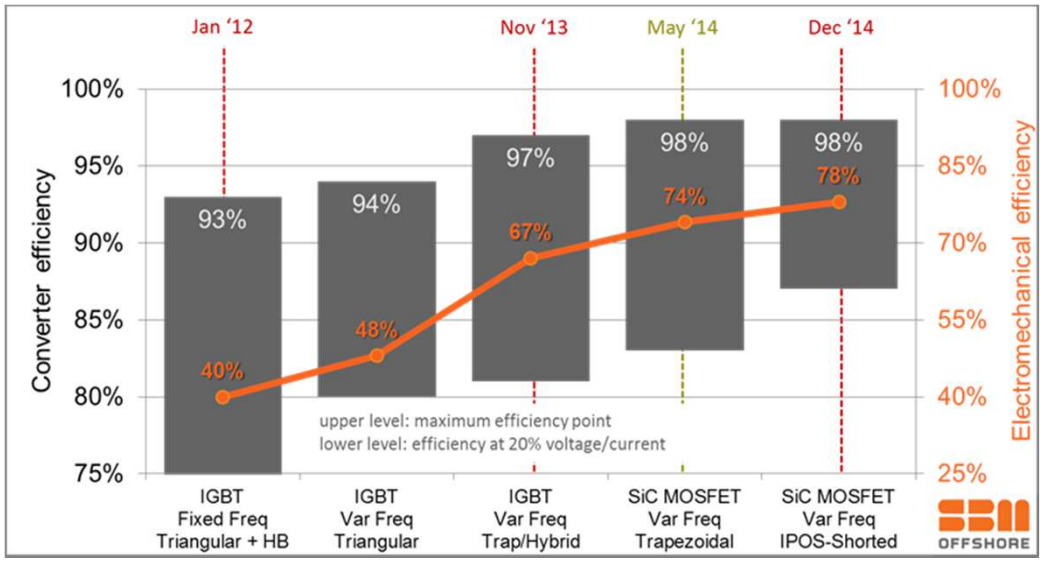
Todorcevic, T.; van Kessel, R.; Bauer, P.; Ferreira, J.A., "A Modulation Strategy for Wide Voltage Output in DAB-Based DC–DC Modular Multilevel Converter for DEAP Wave Energy Conversion," in *Emerging and Selected Topics in Power Electronics, IEEE Journal of* , vol.3, no.4, pp.1171-1181, Dec. 2015

Todorcevic, T.; Bauer, P.; Ferreira, J.A., "Efficiency improvements using SiC MOSFETs in a dc-dc modular multilevel converter for renewable energy extraction," in *Power Electronics and Motion Control Conference and Exposition (PEMC), 2014 16th International* , vol., no., pp.514-520, 21-24 Sept. 2014

Tests in Power Electronics Lab TU Delft, 2015



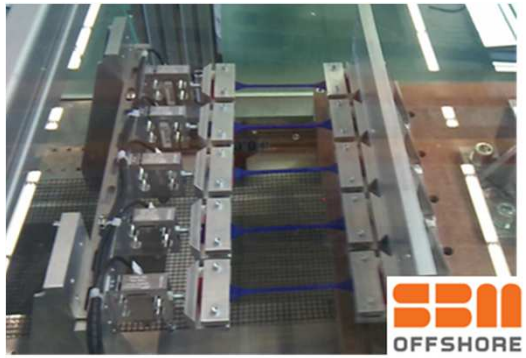
- **2.4kV**
- **12kW**
- **>97%**



R&D

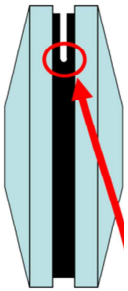
Test facilities

ONGOING RESEARCH & DEVELOPMENT
Test and qualification facilities

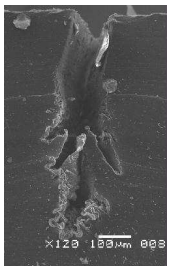


Standard mechanical and electrical testing

- Stress-Strain
- Mechanical fatigue
- Electrical ageing
- Crack growth analysis



Courtesy of Will Mars, Endurica

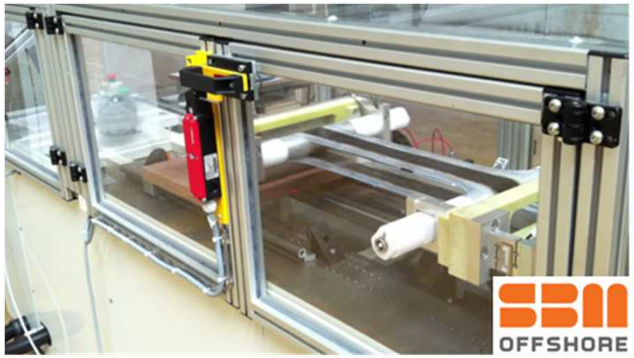


Courtesy of Ecole Centrale de Nantes

Large Power energy harvesting rig

- Energy output up to 1 kW
- Film quantity up to 1000 m
- Voltage up to 10 kV
- Film or ring shape
- Passive & Active PTO technologies
- High precision and high frequency acquisition

→ Energy harvesting validation
→ Ring design validation
→ Power electronics validation



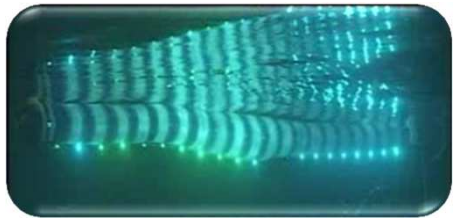
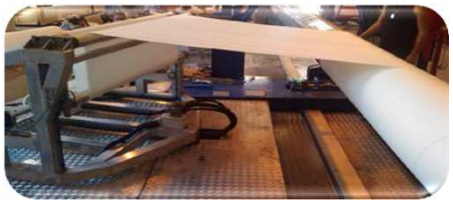
Coupled electro-mechanical fatigue

- Frequency up to 2.5Hz
- Voltage up to 12 kV
- Film or ring shape
- Real operating cycles (combined mechanical + electrical)
- Health monitoring

→ Lifetime estimation
→ Ring design validation (long term)

SBM S3 WEC

Gen 2 devices: the way to reduce LCOE

Engineering	Procurement & Construction	Installation	Operations & Maintenance
			
Rigid Structure & inappropriate PTO	Extensive Construction	Heavy lift & Installation	Periodic maintenance
⇩	⇩	⇩	⇩
Fatigue Friendly structure Frequency indep. distrib. PTO Large absorption bandwidth	Industrial Roll to Roll	Easier load out & Installation	Run Until Failure
			
Reduced CAPEX & Improved efficiency	**True Ramp up to commercialization**	**Reduced Cost of Installation**	**Reduced OPEX**

Lower Cost Of Electricity

SBM S3 WEC – A Paradigm Shift

- First milestones passed:
  - Proof of concept (direct power gen with EAP in water demonstrated + Wave2Wire model developed and validated)
  - Large scale power electronics topology developed
  - EAP control algorithms developed
  - Generator ring design validated
  - EAP performance and large scale manufacturing
  - Comprehensive business model
- Next step: scaled prototype at sea
- Developments up to full technical and commercial maturity will require significant investment.
  Partners will be sought to participate

SBM S3 WEC – A Paradigm Shift

- **All the material on SBM S3 Wave Energy Converter presented during the KIVI event on the 18th of February 2016 is available in the references below:**

1. Andritsch, T.; Morshuis, P.H.F.; Smit, J.J.; Jean, P.; van Kessel, R.; Wattez, A.; Fourmon, A., "Challenges of using electroactive polymers in large scale wave energy converters," in Electrical Insulation and Dielectric Phenomena (CEIDP), 2012 Annual Report Conference on , vol., no., pp.786-789, 14-17 Oct. 2012
2. A. Babarit, B. Gendron, J. Singh, C. Melis and P. Jean , "Hydro-elastic modelling of an electro-active wave energy converter" , Proc. ASME 32nd Int. Conf. Ocean, Offshore Arctic Eng., vol. 9 , pp.V009T12A033-1 -V009T12A033-9
3. Philippe Jean ; Ambroise Wattez ; Guillaume Ardoise ; C. Melis ; R. Van Kessel ; A. Fourmon ; E. Barrabino ; J. Heemskerk ; J. P. Queau; Standing wave tube electro active polymer wave energy converter. Proc. SPIE 8340, Electroactive Polymer Actuators and Devices (EAPAD) 2012, 83400C (April 26, 2012)
4. Rick van Kessel ; Ambroise Wattez ; Pavol Bauer; The effect of converter efficiency on DEAP-based energy conversion: an overview and optimization method. Proc. SPIE 9056, Electroactive Polymer Actuators and Devices (EAPAD) 2014, 90561D (March 8, 2014)
5. van Kessel, R.; Czech, B.; Bauer, P.; Ferreira, J.A., "Optimizing the dielectric elastomer energy harvesting cycles," in IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society , vol., no., pp.1281-1286, 7-10 Nov. 2010
6. Rick van Kessel ; Ambroise Wattez ; Pavol Bauer; Analyses and comparison of an energy harvesting system for dielectric elastomer generators using a passive harvesting concept: the voltage-clamped multi-phase system. Proc. SPIE 9430, Electroactive Polymer Actuators and Devices (EAPAD) 2015, 943006 (April 1, 2015)
7. Todorcevic, T.; van Kessel, R.; Bauer, P.; Ferreira, J.A., "A Modulation Strategy for Wide Voltage Output in DAB-Based DC–DC Modular Multilevel Converter for DEAP Wave Energy Conversion," in Emerging and Selected Topics in Power Electronics, IEEE Journal of , vol.3, no.4, pp.1171-1181, Dec. 2015
8. Todorcevic, T.; Bauer, P.; Ferreira, J.A., "Efficiency improvements using SiC MOSFETs in a dc-dc modular multilevel converter for renewable energy extraction," in Power Electronics and Motion Control Conference and Exposition (PEMC), 2014 16th International , vol., no., pp.514-520, 21-24 Sept. 2014

- **SBM will present its S3 WEC at the OTC conference in May 2016, Houston.**

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